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TANK TESTS OF A FAMILY OF FLYING-BOAT HULLS

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SUMMARY

This report presents towing tests made in the N.A.C.A. tank of a parent form and five variations of a flying-boat hull. The beams of two of the derived forms were made the same as that of the parent and the lengths changed by increasing and decreasing the spacing of stations. The lengths of two others of the derived forms were made the same as that of the parent while the beams were changed by increasing and decreasing the spacing of buttocks, all other widths being changed in proportion. The remaining derived form has the same length and beam as the parent, but the lines of the forebody were altered to give a planing bottom with no longitudinal curvature forward of the step.

The test data were analyzed to determine the minimum resistance and the angle at which it occurs for all speeds and loads. The results of this analysis are given in the form of nondimensional curves for each model.

The effect of variation in over-all size, as indicated by a "complete" test on any given hull, is pointed out. The effect of changing length alone by the spacing of stations, of changing beam alone by the spacing of buttocks, as well as the effects of the changes in length-beam ratio and longitudinal curvature that result from these operations are discussed. The difficulties encountered in interpreting test results of systematic families derived by the method used are emphasized. Further studies are suggested in which changes in the variable under consideration would not be obscured by secondary changes in other important variables.

INTRODUCTION

The effects of changes in hull dimensions and shape of under-water volume for displacement-type vessels have been extensively investigated in towing tanks. Systematic series of models based upon single sets of lines with progressive changes in the factors that affect resistance have been of great assistance in developing more efficient forms.

Similar methods suggest themselves for towing-tank research conducted for the purpose of improving the water performance of seaplanes. The different character of seaplane hull operation, however, leads to dissimilarities in the factors that affect resistance. During the take-off, the speed increases from zero to the point at which flight is attained; the load on the water decreases as the load is transferred from the water to the wings and, for the greater part of the take-off, is supported by hydrodynamic rather than hydrostatic forces. The under-water form presented to the flow of the water is therefore constantly changing. Properties of the hull at rest, such as initial trim, draft, and distribution of displacement, become of minor significance. As hydrodynamic and aerodynamic forces develop, the seaplane rises bodily and runs dry above the chines; hence the flow is affected principally by the amount and distribution of the under-water surface rather than the volume.

One systematic method of varying the amount and distribution of surface below the chines consists of changing the spacing of stations or of buttocks. Using this method of variation on a single parent form, the Committee has investigated the effects of changing length alone holding beam constant and of changing beam alone holding length constant. The series was based on N.A.C.A. Model 11, which represents a hull for a flying boat, and on five forms derived from it. The six models were tested during 1932-33 in the N.A.C.A. tank at Langley Field, Va., by the "complete" method used at the tank for fundamental research on hull forms. Test data for two of the models, N.A.C.A. Model 11 and Model 11-A, have been published as technical notes of the Committee (references 1 and 2). The present paper includes the test results of the series as a whole with an analysis of the effects of the variations introduced into the series.

DESCRIPTION OF MODELS

General.- The series investigated consists of a family of five models made up of the parent form, Model 11, and four variations embodying changes in length and beam - Models 12, 13, 14, and 15. Model 11-A was introduced later to study the effect of forebody curvature. The lines and offsets of Model 11 are given in reference 1 and those of Model 11-A in reference 2. The variations in dimensions among the first five models of the family and their effect on the shapes are indicated in figure 1. Models 11, 12, and 13 form a length series in which beam is held constant while Models 11, 14, and 15 form a beam series in which length is held constant.

Such changes in dimensions will slightly alter the position of the water line at rest and the center of buoyancy for a given load. As explained in the introduction, however, the distribution of buoyancy, important in the case of ship models throughout their speed range, loses its significance for seaplane hull models except at the lowest speeds.

The parent form.- Model 11 was designed expressly for the investigation described herein. It is of the type most generally used in the United States, having a transverse step a short distance aft of the center of gravity, a short afterbody terminating in a vertical sternpost, and an elevated stern for the support of the airplane tail surfaces. For simplicity, the sides of the model were made vertical above the chines and the deck was made coincident with the horizontal base line used in the construction of the model. The bottom sections are straight from keel to chine except near the bow, where they become arched for seaworthiness. Near the step and aft of the step the angle of dead rise is constant.

It will be seen that the planing bottom forward of the step has more longitudinal upward curvature than is usually found in current practice. This characteristic causes the geometric form of this area to change appreciably with the change of longitudinal dimensions decided upon for the length series, with correspondingly more marked effects on resistance, whereas the extension and contraction of a bottom with no curvature near the step would have had a negligible effect on resistance except at the slowest speeds.

Length series.- Model 12 was derived from the parent by uniformly increasing the distance between stations. The resulting form has a greater over-all length, less fore-and-aft curvature of the forebody, and reduced values of longitudinal angles, the most important angle so reduced being the keel angle aft of the step. Model 13 was derived by decreasing the station spacing, giving an opposite variation to the factors affected, namely, shorter length, more curvature, and greater longitudinal angles. Each station is of itself unchanged; hence the dead rise and the transverse distribution of surface remain constant.

Beam series.- Model 14 was derived from the parent by increasing the buttock spacing and beam in proportion. This operation reduced the dead-rise angle. In Model 15 the buttock spacing and beam were reduced, and the dead-rise angle thereby increased. In this series the profile of keel and chine as well as the true shape of the buttocks remained constant.

Model 11-A.- As explained in reference 2, this model was derived from the parent by removing the curvature from the forebody keel, buttocks, and chines as far forward of the step as was practicable. The portion aft of the step was unchanged.

The following table summarizes the values of the basic variables of length and beam chosen and the effect of their change on the other important characteristics of the hulls:

Model	Length in.	Beam in.	Length-beam ratio	Dead-rise angle	Angle between forebody and afterbody keels	Relative forebody curvature for'd of step
11	96	17	5.65	22° 30'	5° 30'	1.000
12	102	17	6.00	22° 30'	5° 11'	.885
13	90	17	5.30	22° 30'	5° 56'	1.137
14	96	19	5.05	20° 20'	5° 30'	1.000
15	96	15	6.40	25° 10'	5° 30'	1.000
11-A	96	17	5.65	22° 30'	6° 30'	0

Construction.- All the models were made of laminated mahogany to a working tolerance of ±0.02 inch. They were painted with several coats of gray-pigmented varnish and carefully rubbed to give a smooth finish.

APPARATUS AND TEST METHOD

The N.A.C.A. tank with its associated apparatus is described in reference 3. The present tests employed the smaller towing gear, which permits a reasonable degree of accuracy of measurement for the sizes of the models used.

Data were obtained over a range of speed, load, and trim angle by the complete method (see reference 1), which permits an extensive comparison of results unhampered by any arbitrary design values of gross load and get-away speed. In this method, load on the water and trim angle are made the independent test variables for which simultaneous values of speed, resistance, trimming moment, and draft are recorded for a large number of constant-speed runs of the towing carriage.

RESULTS

The data from the tests of Models 12, 13, 14, and 15, corrected by the usual tares as described in reference 3, are presented in figures 2 to 22 as curves of resistance and trimming moment plotted against speed, with load on the water as a parameter. No tabular data are given for the family of hulls, as the models are not particularly good for design purposes and the graphical presentation is satisfactory for comparison. The resistance includes the air drag of the model, as explained in reference 1. The curves of test data for Models 11 and 11-A have been published previously in references 1 and 2; hence they are not included here.

Figures 23 to 34 show the characteristics at the best trim angles of all the models, including 11 and 11-A, reduced to nondimensional form. The coefficients used are defined as follows:

$$C_\Delta = \frac{\Delta}{w\,b^3}$$

$$C_R = \frac{R}{w\,b^3}$$

$$C_V = \frac{V}{\sqrt{g\,b}}$$

where Δ is the load on the water, lb.

   R,   resistance, lb.

   V,   speed, ft. per sec.

   w,   weight of water per unit volume, lb. per cu.ft,

   b,   beam, ft.

   g,   acceleration of gravity, ft. per sec.^{2}

These coefficients may be used with any other consistent system of units.

The application of the nondimensional data is discussed in detail in reference 1. In order to facilitate comparison of the various models, the load-resistance ratio calculated from the best-angle data is plotted against the load coefficient for several speed coefficients in figures 35 to 40. It should be noted that the use of the beam as the characteristic dimension in these coefficients causes hulls of different length-beam ratios to be compared on the basis of equal beams but different lengths.

PRECISION

The test data are believed to be correct within the following approximate limits:

Load	±0.3 lb.
Resistance	±0.1 lb.
Trimming moment	±1.0 lb.-ft.
Trim angle	+0.1°
Speed	±0.1 ft. per sec.

DISCUSSION

The family of hulls presented in this report was designed primarily to investigate the effect of variation in the length of hull when the beam is held constant, and in the beam when the length is held constant. The manner in which the variation was made, however, introduced secondary changes in the longitudinal curvature of the forebody, in the longitudinal angle between the forebody and the afterbody, and in the angle of dead rise. As a result, the effect of a change in any one of the design variables is difficult to separate from the effects of the accompanying variations in other factors. This discussion is an attempt to segregate the influence of the individual factors, in so far as the results of this series of tests are susceptible of such treatment.

Variation of Over-All Size

The effects on take-off performance produced by changes in the over-all dimensions of a hull of given form, as applied to a particular seaplane, are pointed out in reference 1. The analysis of the data for Model 11 given there showed that increasing the hull size for a given design will generally reduce the resistance at the hump, but will increase it at speeds near get-away. All the models of this series show this same tendency, as can be seen from figures 35-40. At the hump speed, decreasing the load coefficient C_Δ, that is, increasing the size of hull for a given load, increases the value of Δ/R in every case. In the high-speed range, as shown by the curves for speed coefficients of 4.5 and 6.0, decreasing the load coefficient reduces the value of Δ/R, giving higher resistance for a given load. It is therefore evident that the variations in geometric form among the models of this series do not alter the general rule that a large hull for a given load is favorable to low hump resistance but causes high resistance near get-away.

Variation of Length Holding Beam Constant

Increasing the length alone shows the same tendency to decrease the hump resistance and increase the resistance at high speeds that is produced by an increase in over-all dimensions. The curves of figure 41 give the Δ/R ratio plotted against load in pounds at three typical speeds for

Models 11, 12, and 13, which comprise the length series.
Increasing the length gives a marked improvement in Δ/R
at the hump. The decrease in Δ/R at high speed (40 feet
per second) resulting from increased length is not very
great.

The secondary effects of changing the length by al-
tering the station spacing, as was done in the series of
Models 11, 12, and 13, are changes in forebody curvature
and in the angle between the forebody and afterbody. If
the test results of Models 14 and 15 are converted to a
beam of 17 inches, another length series is represented
in which the angle between the forebody and afterbody is
the same for all the models, and in which the curves of
the forebody buttocks are geometrically similar. The ac-
tual radii of curvature at corresponding stations in this
series will, of course, be proportional to the length of
the model. The values of Δ/R for the three models, all
converted to 17-inch beam, are plotted against load for
three typical speeds in figure 42. Again, increasing the
length improves the Δ/R ratio at hump speed and at
speeds in the lower part of the planing range. At 40 feet
per second, however, the intermediate length, Model 11,
gave somewhat better results than either of the others.

In both these series of models with the same beam
the increase in length from the shortest to the longest
is accompanied by an increase in the radius of curvature
of the forebody. The following tabulation shows the order
of merit of the five hulls with 17-inch beam, together
with the relative magnitude of the curvature (i.e., the
reciprocal of the radius of curvature). For each speed,
the numeral "1" indicates the hull having the highest
Δ/R, numeral "2", the hull having the next highest, etc.
The length and curvature are expressed in terms of the
ratio of these quantities for each model to the values
for Model 11.

Model	Relative length	Relative curvature	Order of Δ/R		
			at hump	at 25 f.p.s.	at 40 f.p.s.
14	0.895	1.118	4,5	5	4,5
13	.938	1.137	4,5	3,4	1
11	1.000	1.000	3	3,4	2
12	1.062	.885	2	2	3
15	1.133	.883	1	1	4,5

In the cases where two of the models have substantial-
ly the same value of Δ/R, they have been rated equally.

This table does not show conclusively whether it was the length, as such, or the low forebody curvature that had a favorable effect on the longer models. Definite interpretation is further obscured by the variations in dead-rise angle and in the angle between the forebody and the afterbody.

A comparison between Models 11 and 11-A, however, shows the influence of forebody curvature without the obscuring effect of changes in the other variables since the lines of the two models are identical except for the flat planing bottom of Model 11-A. Such a comparison is shown in figure 43. The pronounced improvement of Model 11-A over Model 11 at all speeds and loads shows that, to a large extent, the differences shown in the table may be accounted for by the influence of longitudinal curvature. This conclusion was to be expected from general considerations of the behavior of a hull at planing speeds, because the length of the hull as such has no influence on the form of the planing bottom at speeds above that at which the bow rises out of the water.

The order of merit shown in the table for a speed of 40 feet per second is somewhat more difficult to explain. At this speed Model 11-A is superior to any of the five hulls in the regular family. It would thus appear that the advantage of a flat forebody extends to high speeds. The next best hull, however, is Model 13, which has the highest curvature of the entire family. This model has also the greatest angle between forebody and afterbody; hence the influence of the interfering blister on the afterbody, discussed in references 1 and 4, is reduced. The somewhat complicated effect of the relation between forebody curvature and afterbody clearance probably accounts for the apparently haphazard order of merit of the five hulls at this speed.

Variation of Beam Holding Length Constant

A comparison of Models 14, 11, and 15, which form a series constant in length but varying in beams, is given in figure 44. In this series the longitudinal sections of the three models are the same. The change in spacing of the buttocks, however, causes a change in the angles of dead rise and consequently in the fineness of the water lines near the bow. The curves show that the value of Δ/R at the hump increases slightly with increasing beam. At 25 feet per second the narrower beams give higher values

of Δ/R , except that for loads above 47 pounds Model 15
shows poorer performance than Model 11. At 40 feet per
second the value of Δ/R is increased by decreasing the
beam for all loads.

Another series of hulls constant in length but vary-
ing in beam could be obtained by comparing the test re-
sults of Models 12 and 13, converted to 96-inch length,
with those of Model 11. The maximum variation in beam
given by this series is only about half as great as that
for the series of Models 14, 11, and 15. The significance
of the results is obscured by the fact that the longitudi-
nal profiles of the three models are not similar; hence the
comparison is not included.

Effect of Changes in Individual Design Variables

Length-beam ratio.- The primary variable in the fam-
ily of models under discussion is the ratio of length to
beam. It was hoped that the test results would furnish
the information necessary to establish a definite value
of this ratio giving optimum performance for this type of
hull. The foregoing discussion has given an idea of the
difficulties involved in finding a suitable basis of com-
parison. It is possible, however, to establish the rel-
ative merits of the forms of the various hulls (as dis-
tinguished from size), by applying the results to specific
design problems in the manner described in reference 1.
In order to simplify the comparison, the beams may be se-
lected to give equal resistances at hump speeds; the or-
der of merit of the hulls will then be established by
their relative resistances in the high-speed region, due
account being taken of the probable weight and air drag
of the hull the size of which is thus determined. When
this was done for the models of the present family, they
compared as follows:

Order of merit	Model	Relative beam	L/B
1	12	0.955	6.0
2	13	1.058	5.3
3	15	.910	6.4
4	11	1.00	5.65
5	14	1.072	5.05

Obviously, any effect of the length-beam ratio, as
such, is obscured by the influence of the secondary varia-
tions in form.

Longitudinal curvature.- The principal secondary effect appears to be caused by variation of the curvature of the buttocks on the forebody planing bottom. The striking improvement obtained by flattening the forebody, as in Model 11-A, shows the importance of this variable. An explanation of the influence of forebody curvature may be deduced in a general way from the curves of pressure distribution on a planing surface, given in reference 5. These curves show a region of very high pressure at the leading edge of the wetted planing bottom. No data are available on the nature of the distribution on a surface having longitudinal convexity, but it is reasonable to assume that the high concentration of load near the leading edge will be even more pronounced in such a case. Moreover, the buttocks near the leading edge of a curved bottom must have a relatively high angle to the horizontal, otherwise the trailing edge will be at too low an angle to give a reasonable downflow to the wake and there will be a consequent loss of dynamic lift. The high normal force acting on the inclined portion of the buttocks will obviously have a high resistance component, and the value of Δ/R of the planing bottom as a whole will thus tend to be lower than that of a flat surface.

Since some convexity, at least near the bow, appears to be necessary for seaworthiness at low speeds the designer is forced to effect a compromise between the conflicting requirements. It seems evident, however, that perfectly straight buttocks should be carried well forward.

These considerations explain to some extent the difficulty met in trying to establish an optimum length-beam ratio. If the beam is narrow for a given load, a greater length of flat forebody is necessary to keep the high-pressure region from getting up on the bluff portion of the buttocks at the hump speed. If a larger beam is used, the wetted length will be reduced for a given load and speed, and consequently the flat portion of the forebody may be made shorter. Thus, substantially equal values of Δ/R may be obtained with a considerable variation of L/B ratio, provided that there is no pronounced curvature in the region of the planing bottom near the step and that the load for a given beam is properly selected.

Other variables.- Two other design variables, the dead-rise angle and the angle between the forebody and afterbody keels, are altered by the systematic variations used in these tests. The results do not offer a satisfac-

tory basis for segregating the effect of changes in these characteristics, however, and further experiments will be required.

The present tests give some indication that a low angle of dead rise may contribute to high hump resistance if the longitudinal curvature of the hull is excessive. This phenomenon may be seen from the curves of figure 44. The improvement in the value of Δ/R at the hump with increasing beam is less than might be expected, probably because the dead-rise angle, and therefore the fineness of the water lines on the curved part of the forebody, is decreased as the beam is increased.

The angle between the forebody and afterbody keels probably has a pronounced effect on the trimming moments as well as upon the friction resistance caused by the spray striking the afterbody at high speeds. In the present tests, however, changes in this quantity are incidental to changes in length; hence its effects cannot be segregated.

CONCLUDING REMARKS

The results of this series of tests show that systematic variations in hull form, effected by changes in the spacing of either buttocks or stations, are not suitable for the investigation of flying-boat forms. They also show rather conclusively that longitudinal curvature of the forebody should be avoided and that the length-beam ratio of the hull affects its planing performance principally because of the influence of this ratio on the secondary design factors.

Work on the effect of changes in the angle of dead rise and in the angle between the forebody and the afterbody is in progress, and future tests designed to segregate the effect of the length-beam ratio are contemplated. In these studies care will be taken to avoid secondary changes in form that might obscure the effects of the variable under consideration.

Langley Memorial Aeronautical Laboratory,
    National Advisory Committee for Aeronautics,
        Langley Field, Va., January 30, 1934.

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Center of moments

6.31" 6.18"

Models 11,14 & 15

6.31" 6.57"

Model 12

6.31" 5.79"

Model 13

Profiles

96"

8.5"

Model 11

102"

8.5"

Model 12

90"

8.5"

Model 13

96"

9.5"

Model 14

96"

7.5"

Model 15

Plan forms

14"

22°30'

Models
11,12 & 13

20°20'

Model 14

25°10'

Model 15

Sections at step
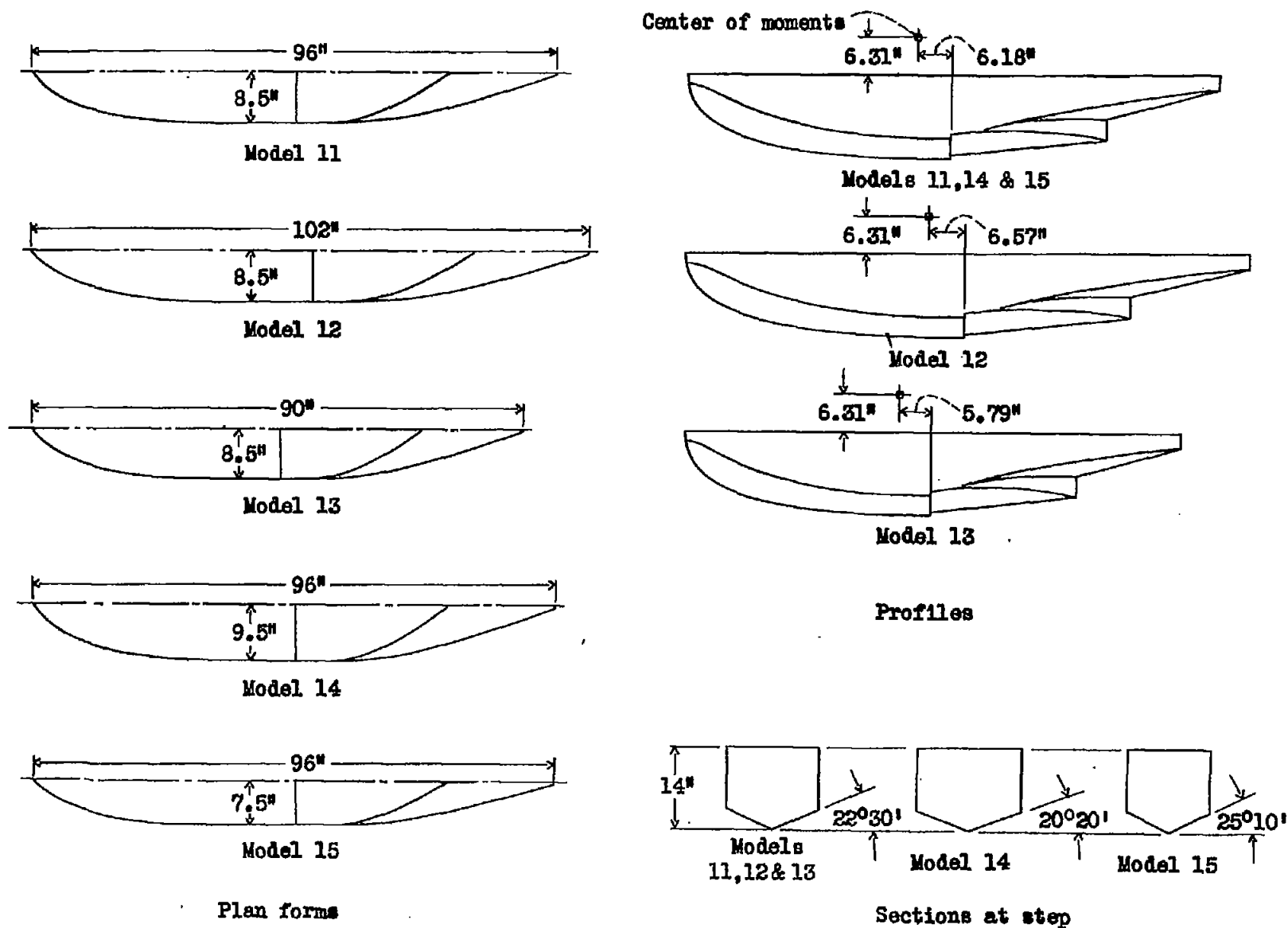
Figure 1.- The family of hulls showing variations in dimensions.

Fig. 1
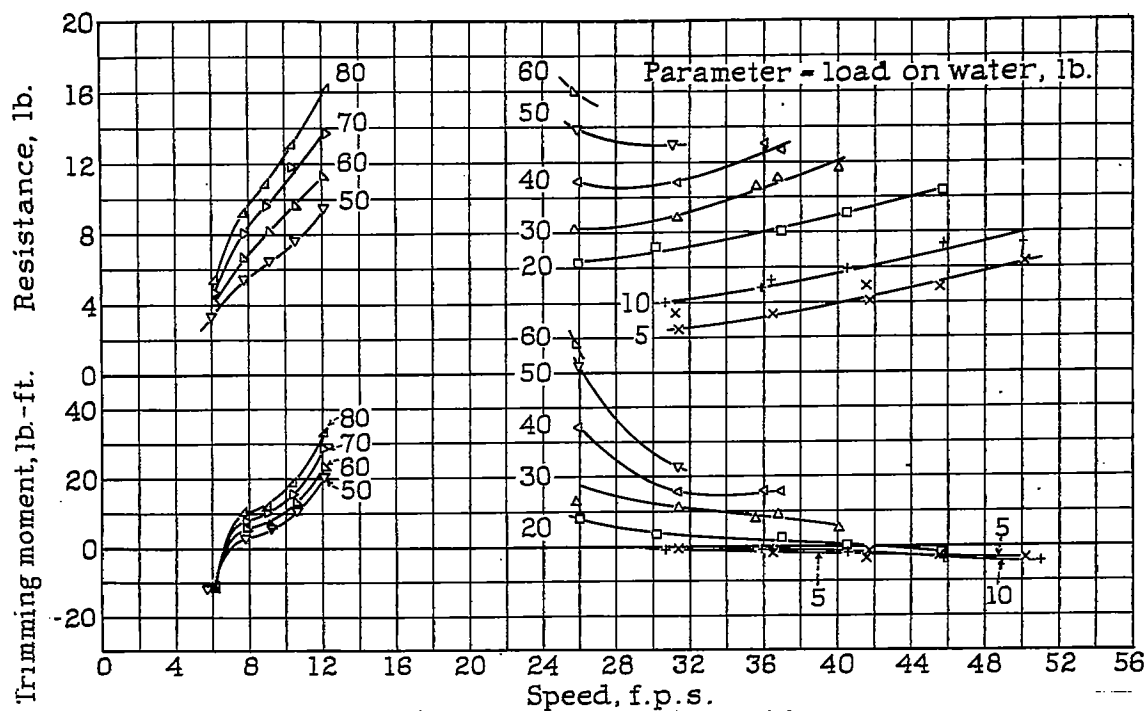
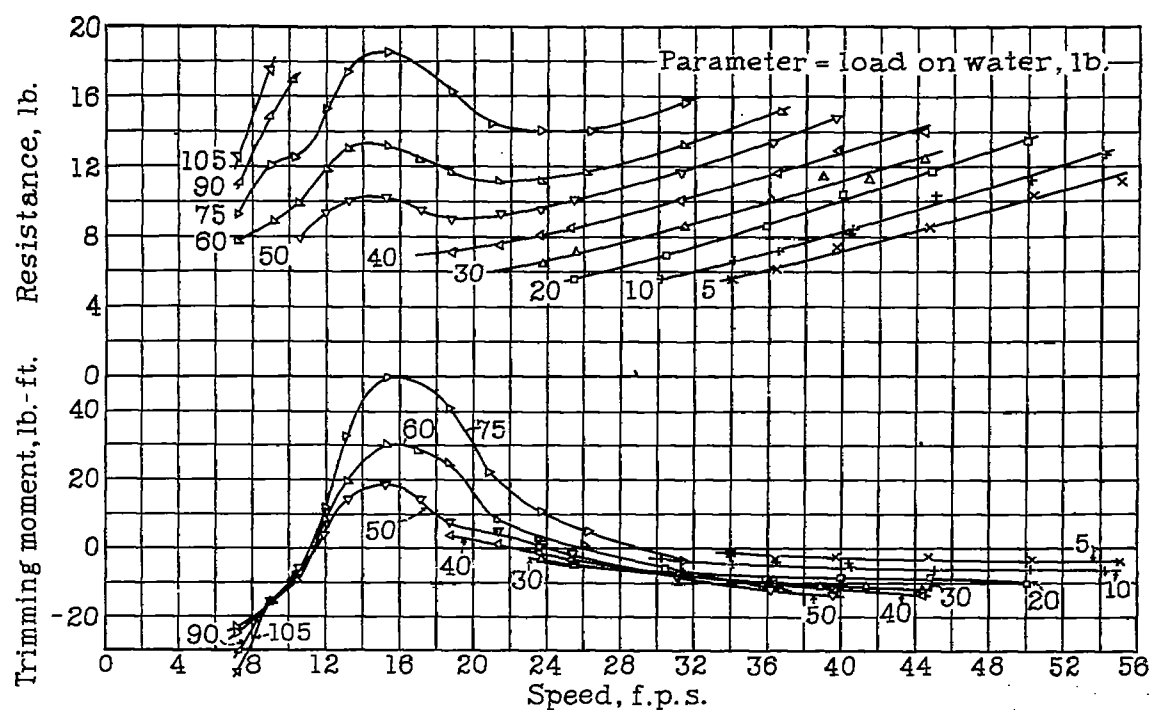Figure 2.- Model 12. Curves of resistance and trimming moment.
Trim angle $\tau = 3°$.
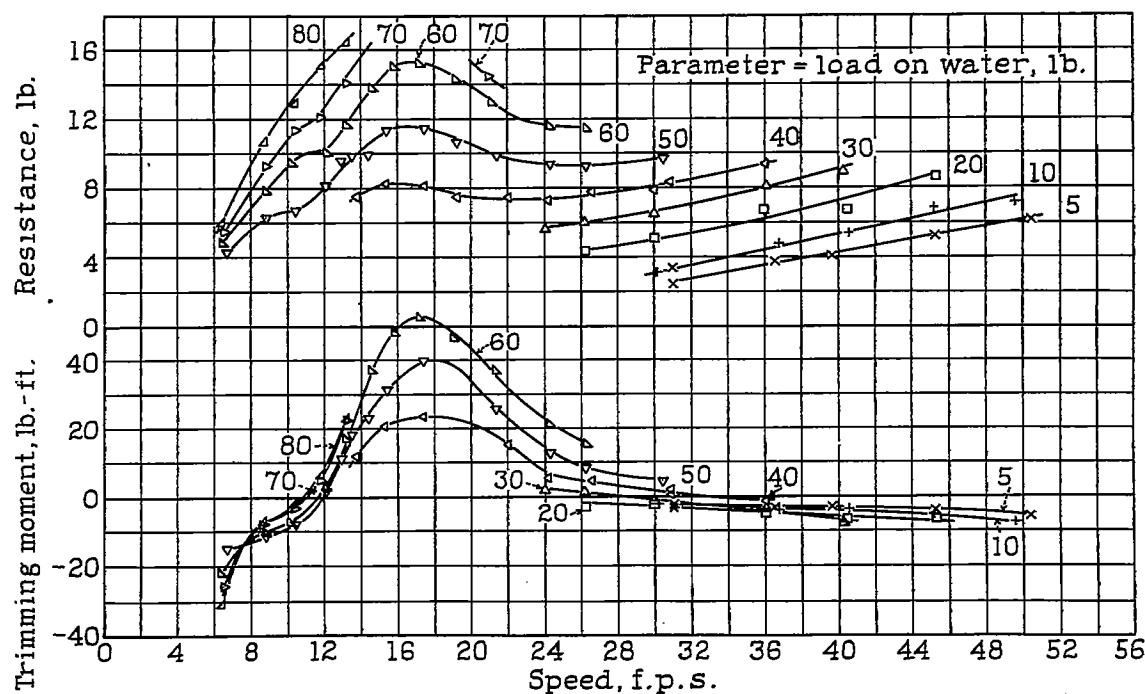
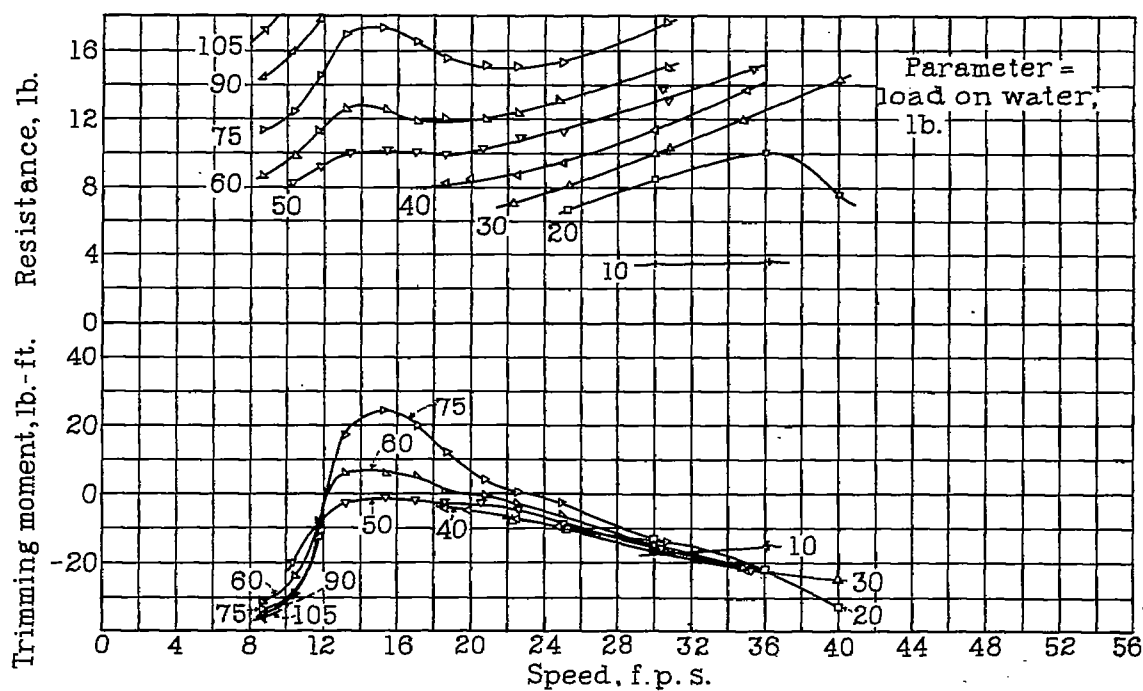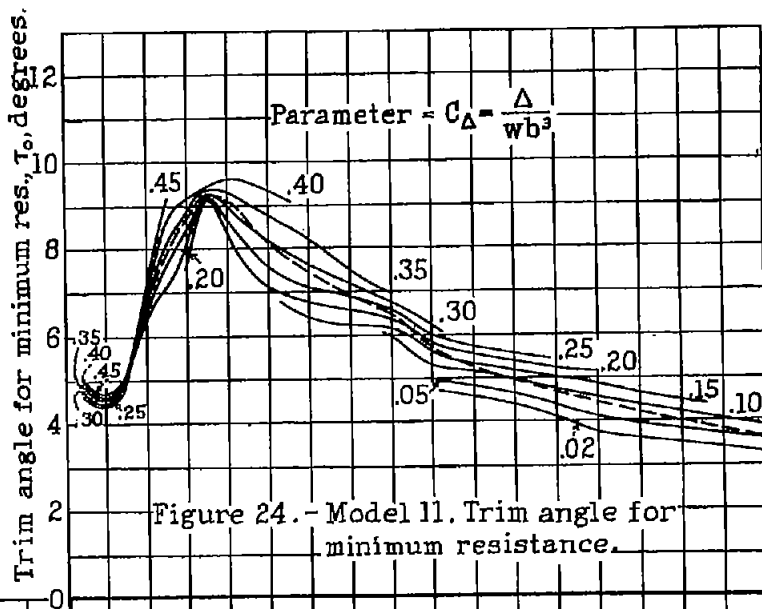Figure 3.- Model 12. Curves of resistance and trimming moment.
Trim angle $\tau = 5°$.
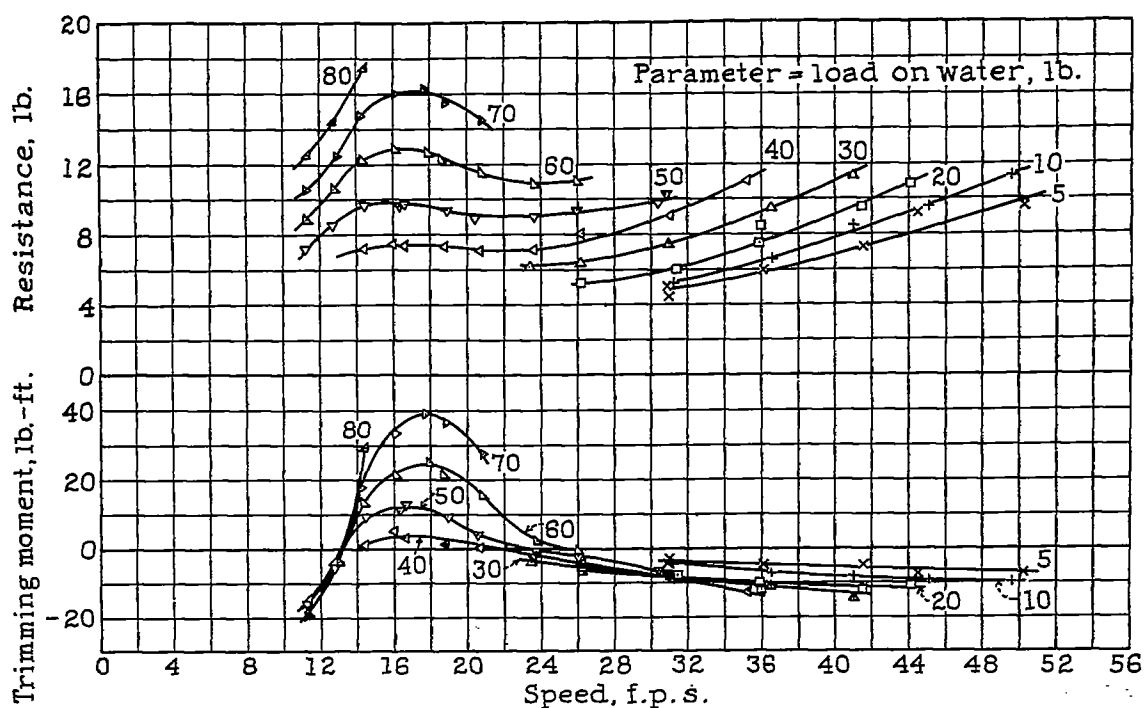
Figure 4.— Model 12. Curves of resistance and trimming moment. Trim angle τ = 7°
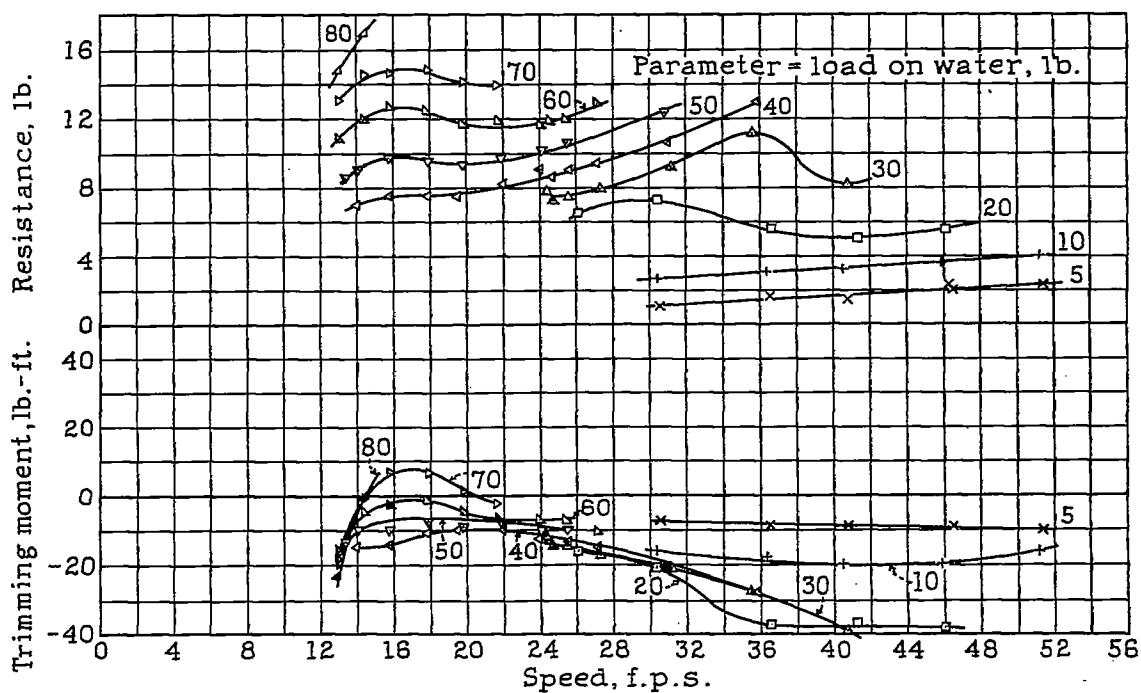
Figure 5.— Model 12. Curves of resistance and trimming moment Trim angle τ ≈ 9°.

Figure 6.- Model 13. Curves of resistance and trimming moment. Trim angle $\tau = 1°$.

Parameter = load on water, lb.

Figure 11.- Model 13. Curves of resistance and trimming moment. Trim angle $\tau = 11°$.

Figure 12.- Model 14. Curves of resistance and trimming moment. Trim angle $\tau = 1°$

Figure 17.- Model 14. Curves of resistance and trimming moment. Trim angle $\tau = 11°$
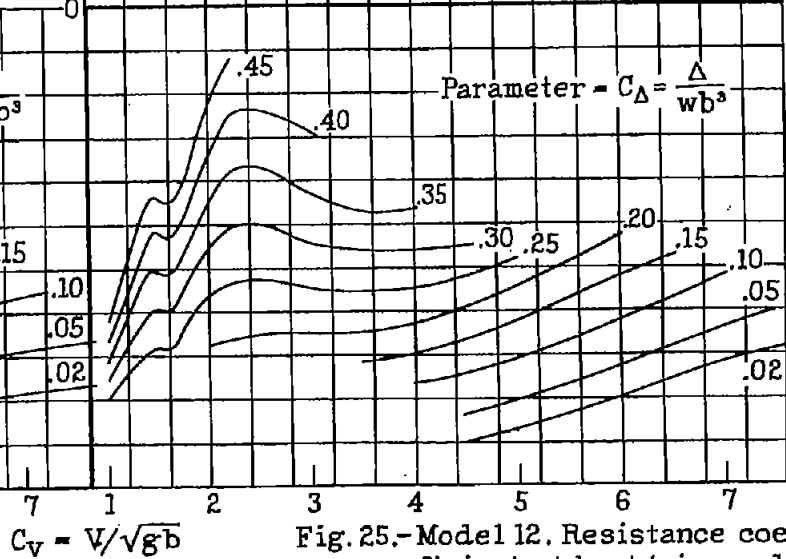
Parameter = load on water, lb.

Speed, f.p.s.
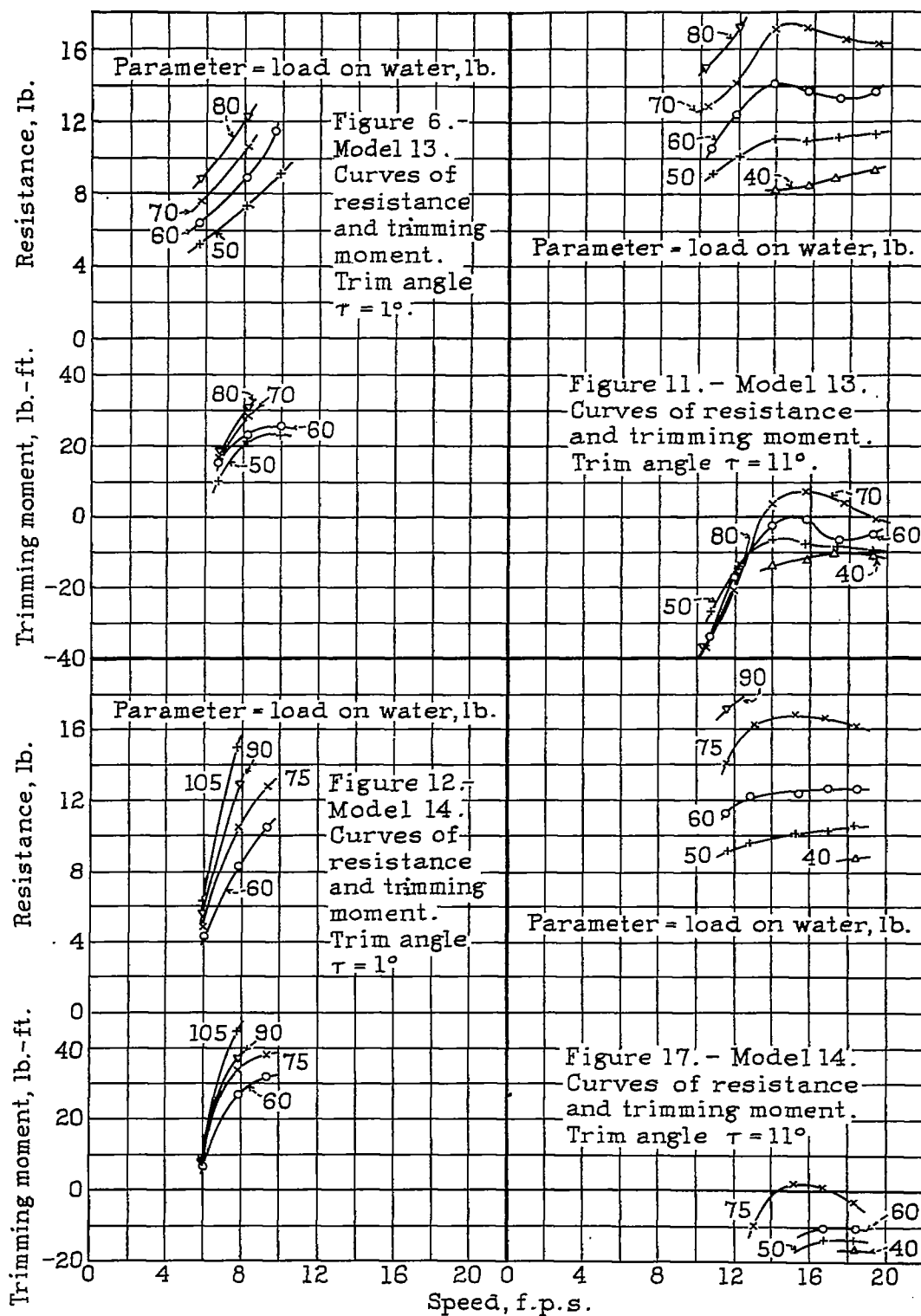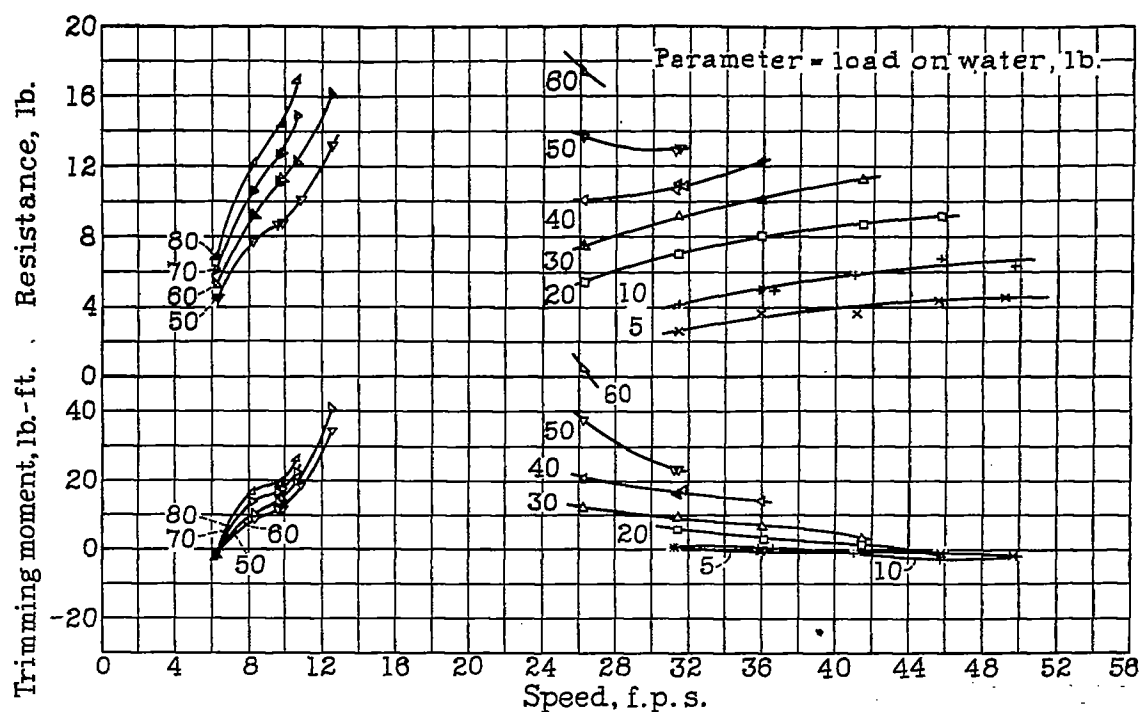
Figure 7.- Model 13. Curves of resistance and trimming moment.
Trim angle $\tau = 3°$
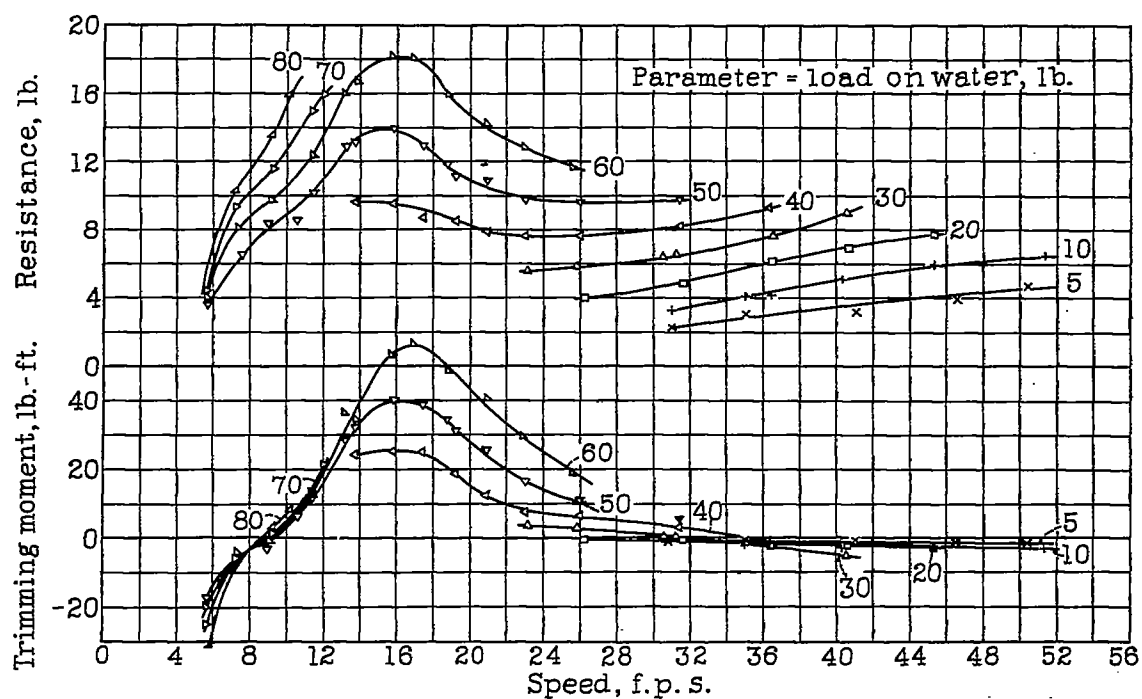
Figure 8. - Model 13. Curves of resistance and trimming moment.
Trim angle $\tau = 5°$.
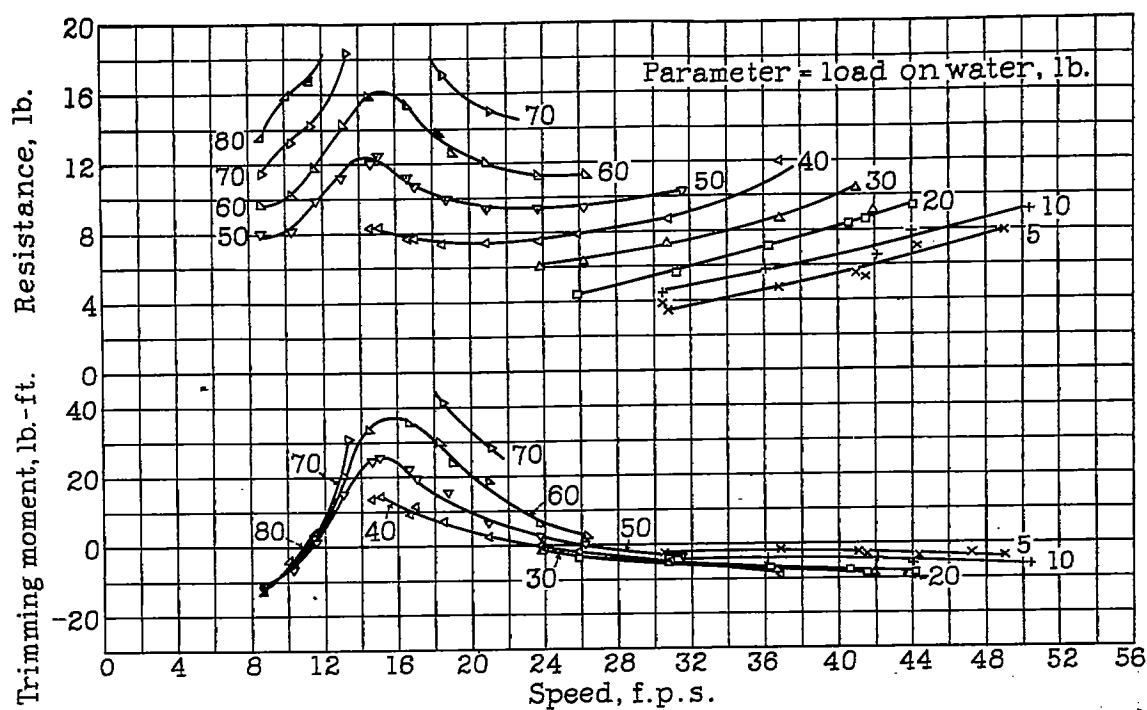
Figure 9.- Model 13. Curves of resistance and trimming moment.
Trim angle $\tau = 7°$.
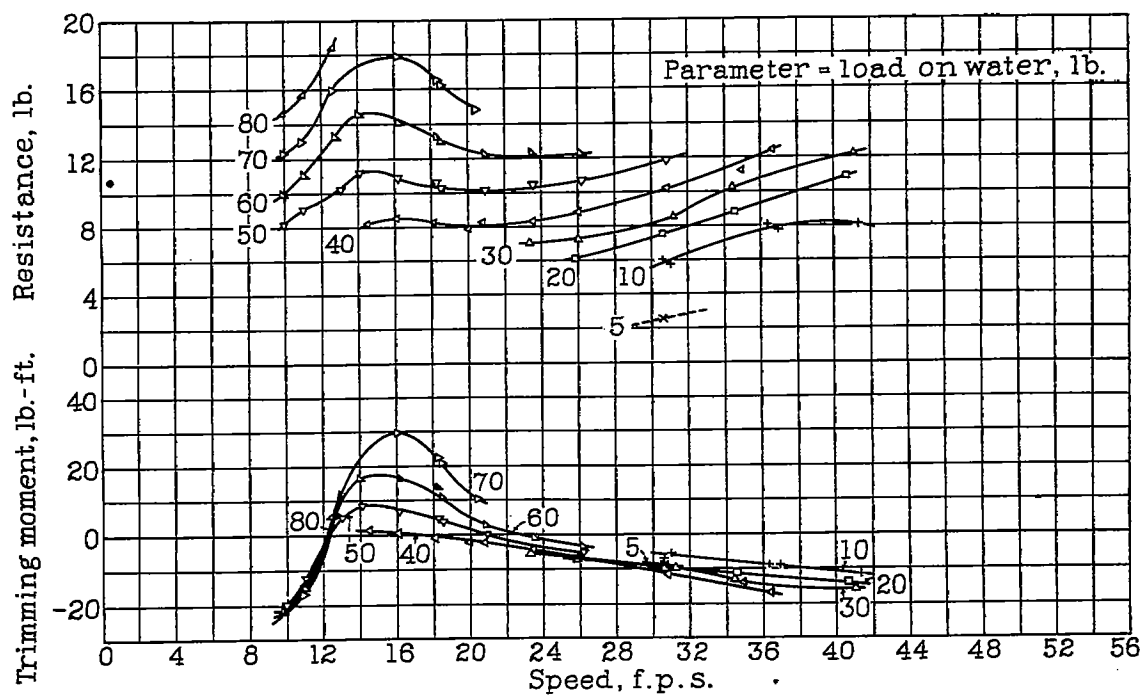
Figure 10.- Model 13. Curves of resistance and trimming moment
Trim angle $\tau = 9°$.
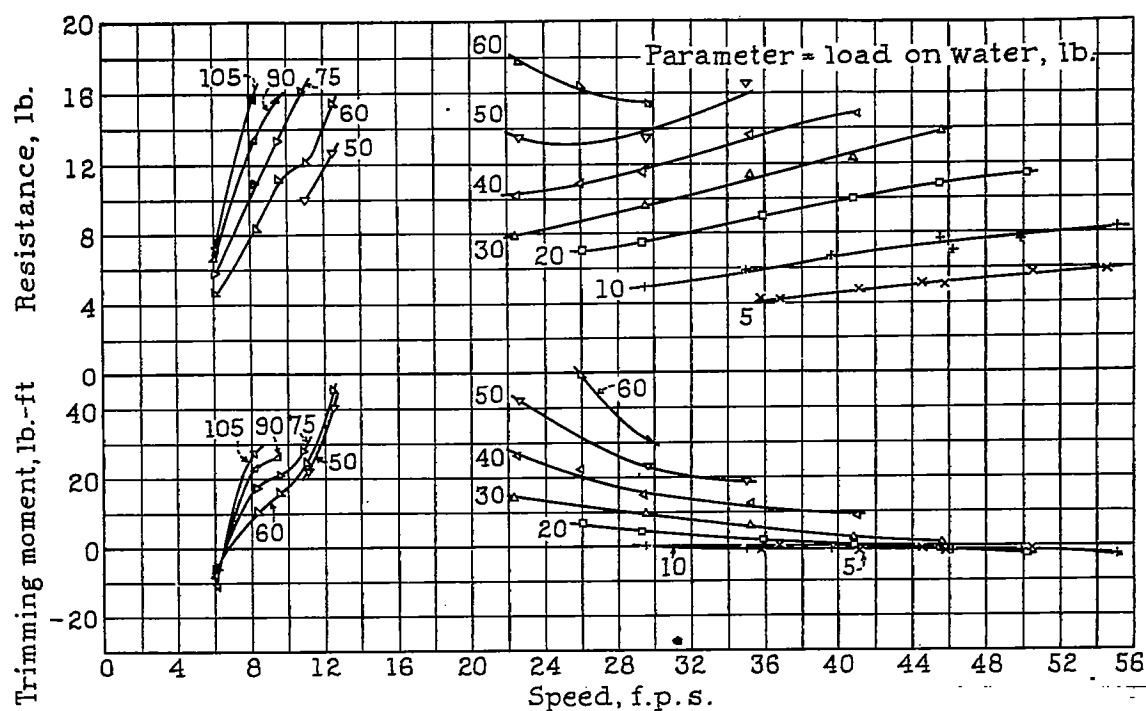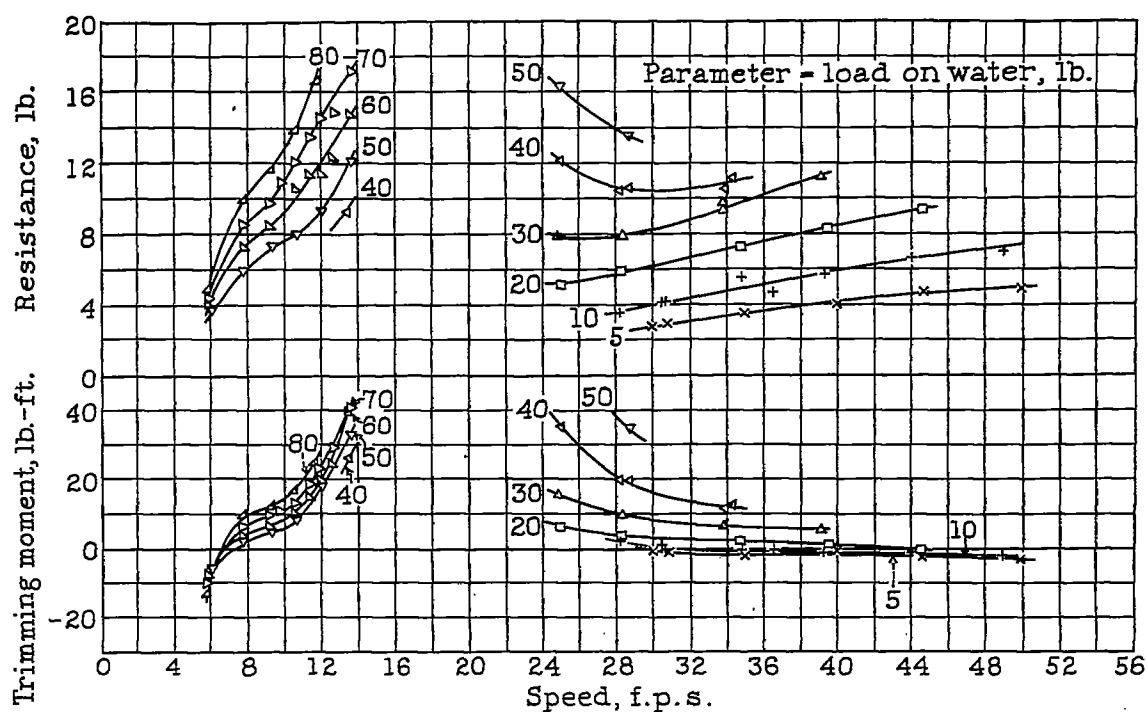
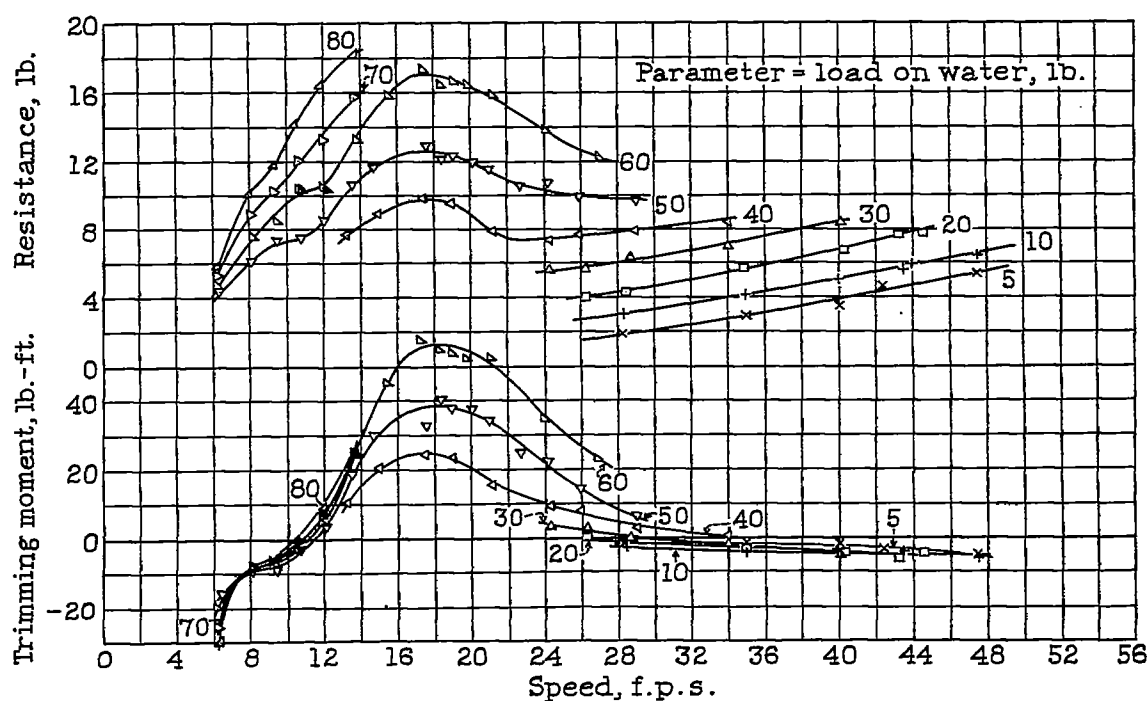Figure 13. - Model 14. Curves of resistance and trimming moment.
Trim angle $\tau = 3°$
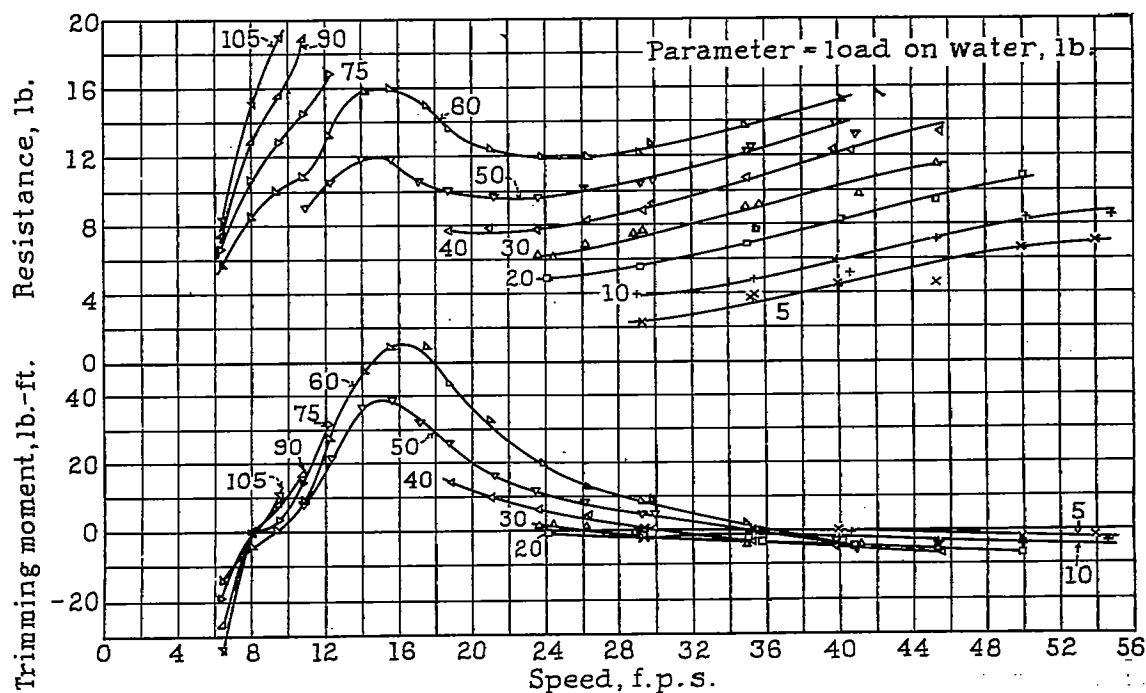
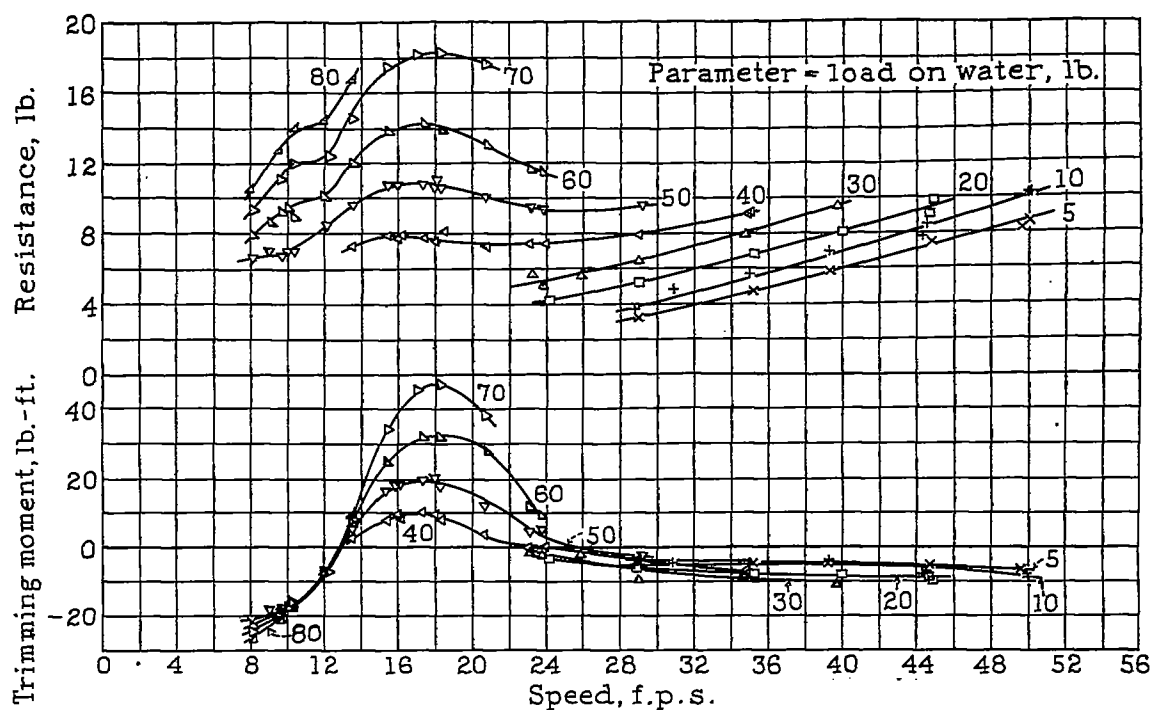Figure 14. - Model 14. Curves of resistance and trimming moment.
Trim angle $\tau = 5°$.

Figure 15.- Model 14. Curves of resistance and trimming moment.
Trim angle $\tau = 7°$

Figure 16.- Model 14. Curves of resistance and trimming moment.
Trim angle $\tau = 9°$.

Trimming moment, lb.-ft. Resistance, lb.

Fig.18.-Model 15. Curves of re-
sistance and trimming
moment.Trim angle τ = 1° and 11°.

Speed, f.p.s.

1° Fixed trim

11° Fixed trim

Parameter=
load on water, lb.

Parameter = $C_\Delta = \dfrac{\Delta}{wb^3}$

Figure 24.- Model 11. Trim angle for
minimum resistance.

Trim angle for minimum res., τ₀, degreees

$C_R = \dfrac{R}{wb^3}$

Parameter = $C_\Delta = \dfrac{\Delta}{wb^3}$

Parameter = $C_\Delta = \dfrac{\Delta}{wb^3}$

$C_V = V/\sqrt{gb}$

Figure 23.- Model 11. Resistance coefficient
at best trim angles.

Fig. 25.-Model 12. Resistance coef-
ficient at best trim angles.

Figure 19. - Model 15. Curves of resistance and trimming moment.
Trim angle $\tau = 3°$

Figure 20.- Model 15. Curves of resistance and trimming moment.
Trim angle $\tau = 5°$.

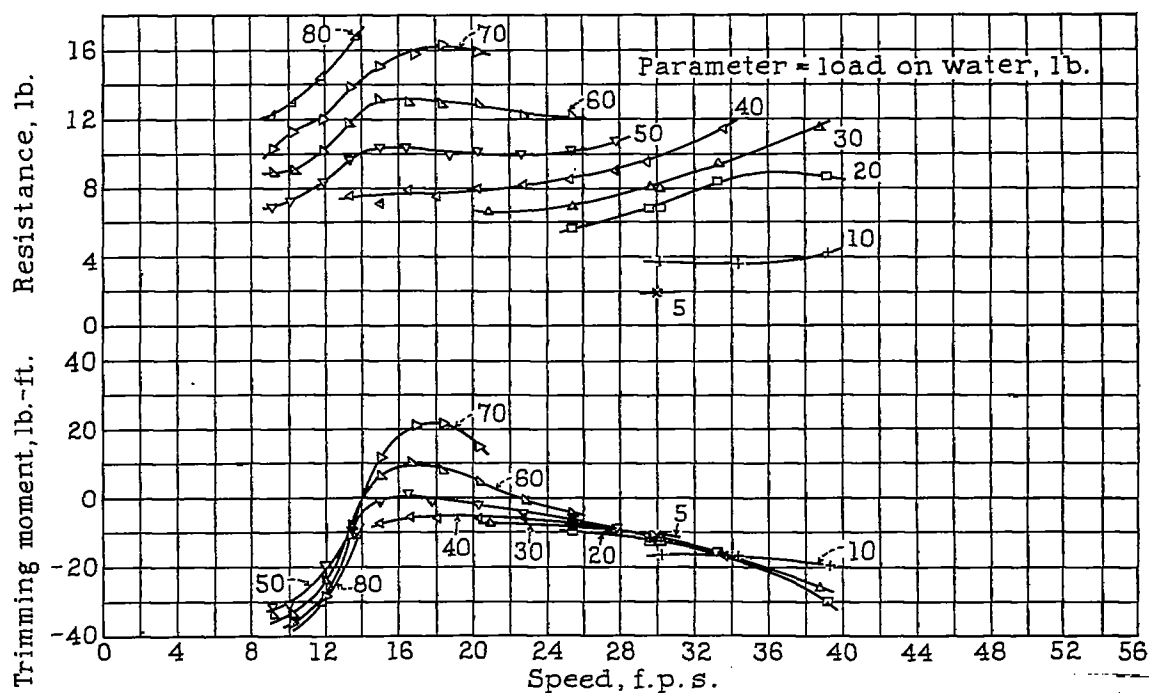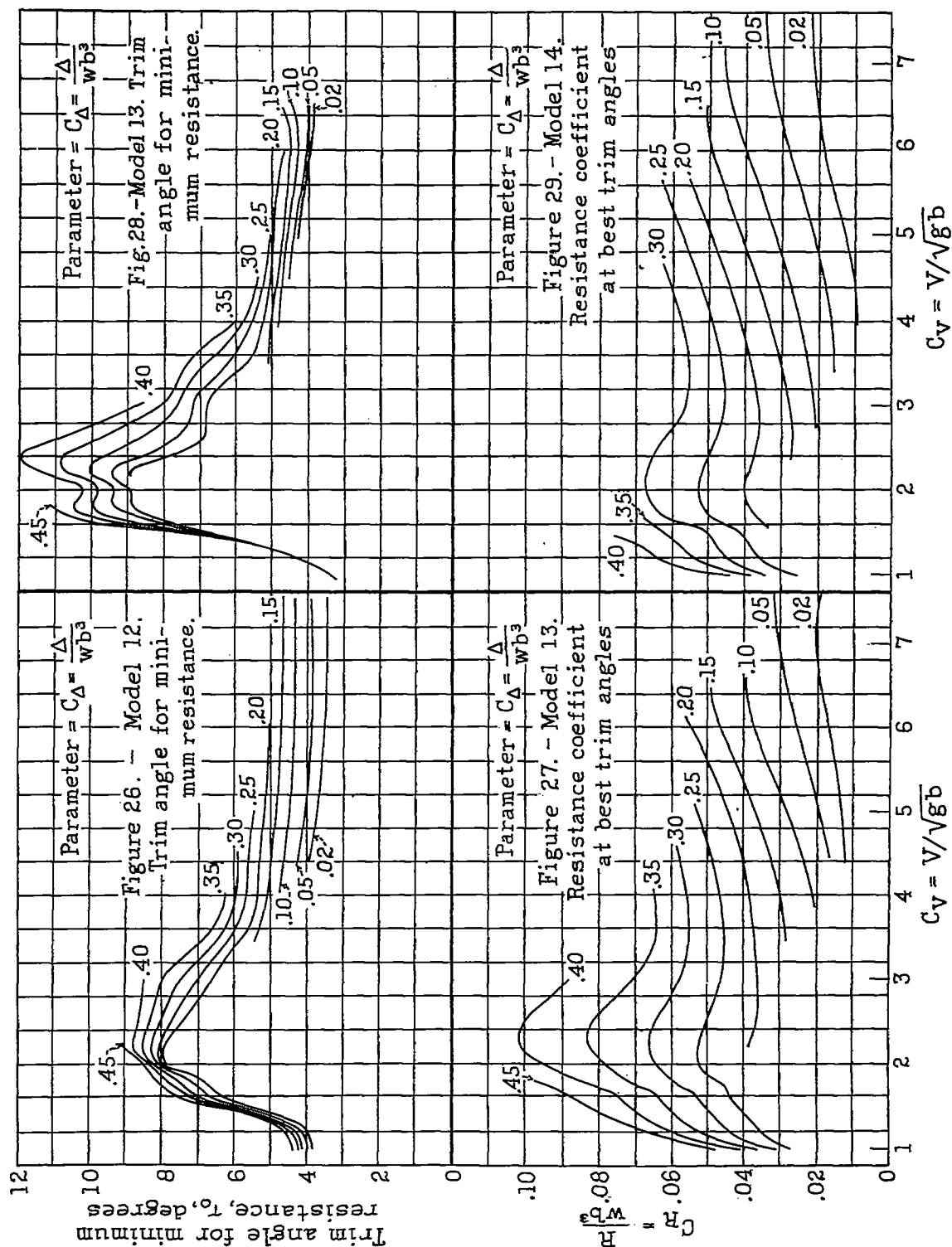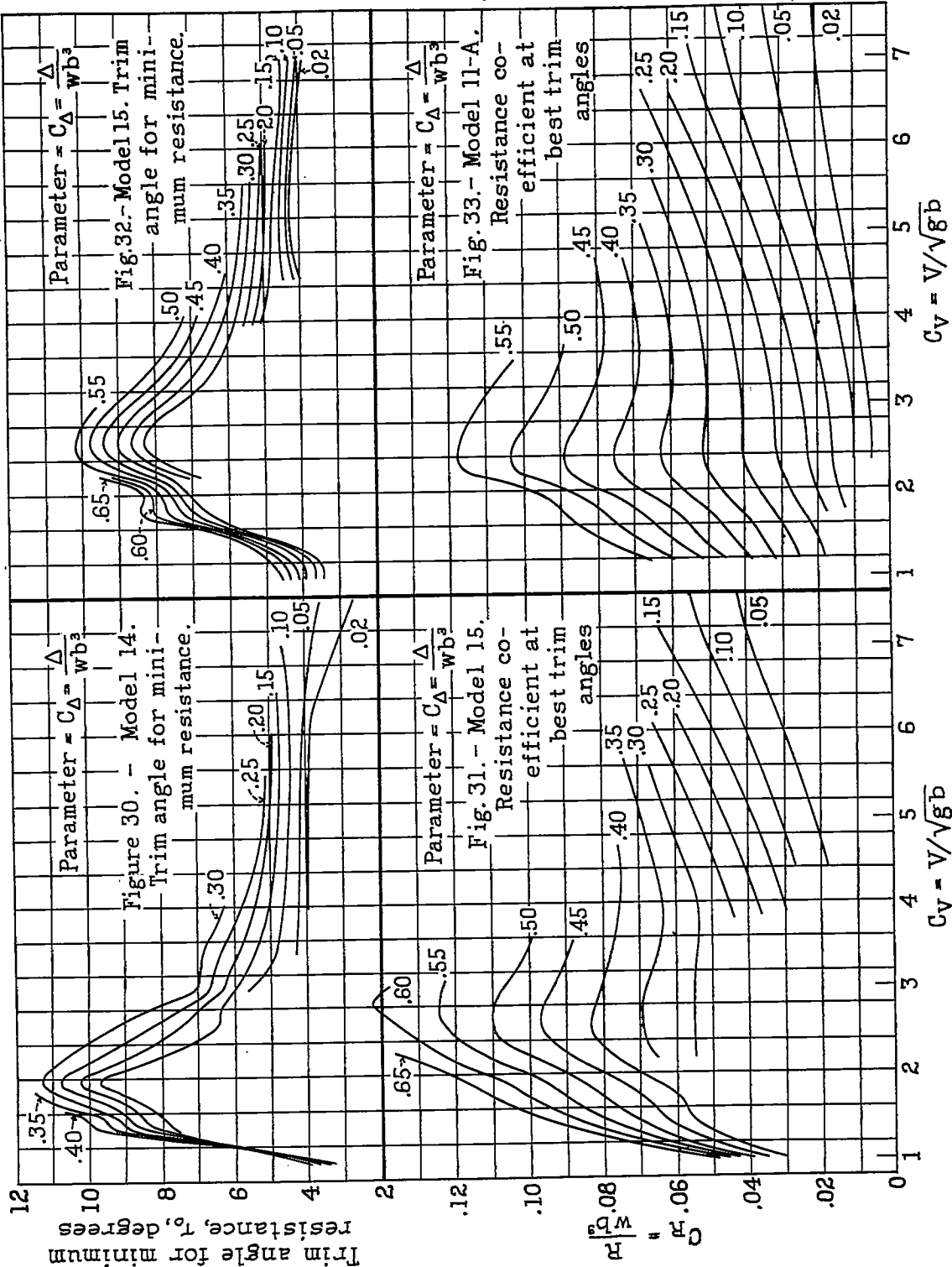Figure 21.- Model 15. Curves of resistance and trimming moment.
Trim angle τ = 7°

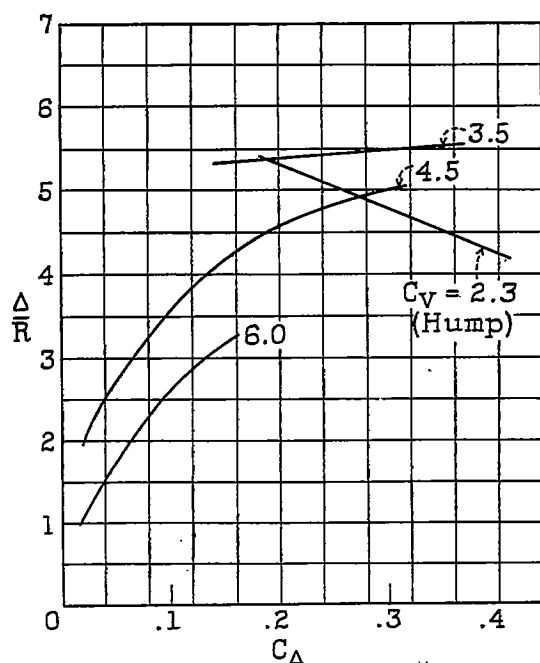Figure 22.- Model 15. Curves of resistance and trimming moment.
Trim angle τ = 9°.

Figure 26. — Model 12. Trim angle for minimum resistance.
Parameter = $C_\Delta = \dfrac{\Delta}{wb^3}$

Fig. 28. — Model 13. Trim angle for minimum resistance.
Parameter = $C_\Delta = \dfrac{\Delta}{wb^3}$

Figure 27. — Model 13. Resistance coefficient at best trim angles
Parameter = $C_\Delta = \dfrac{\Delta}{wb^3}$

Figure 29. — Model 14. Resistance coefficient at best trim angles
Parameter = $C_\Delta = \dfrac{\Delta}{wb^3}$

$C_V = V/\sqrt{gb}$

Trim angle for minimum resistance, τ_0, degrees

$C_R = \dfrac{R}{wb^3}$

Parameter $= C_\Delta = \dfrac{\Delta}{wb^3}$

Fig. 32.- Model 15. Trim angle for minimum resistance.

Parameter $= C_\Delta = \dfrac{\Delta}{wb^3}$

Fig. 33.- Model 11-A. Resistance coefficient at best trim angles

Parameter $= C_\Delta = \dfrac{\Delta}{wb^3}$

Figure 30. - Model 14. Trim angle for minimum resistance.

Parameter $= C_\Delta = \dfrac{\Delta}{wb^3}$

Fig. 31. - Model 15. Resistance coefficient at best trim angles

Trim angle for minimum resistance, T_0, degrees

$C_R = \dfrac{R}{wb^3}$

$C_V = V/\sqrt{gb}$

$C_V = V/\sqrt{gb}$

Figure 35.—Model 11. Effect of C_Δ on Δ/R at best trim angles.
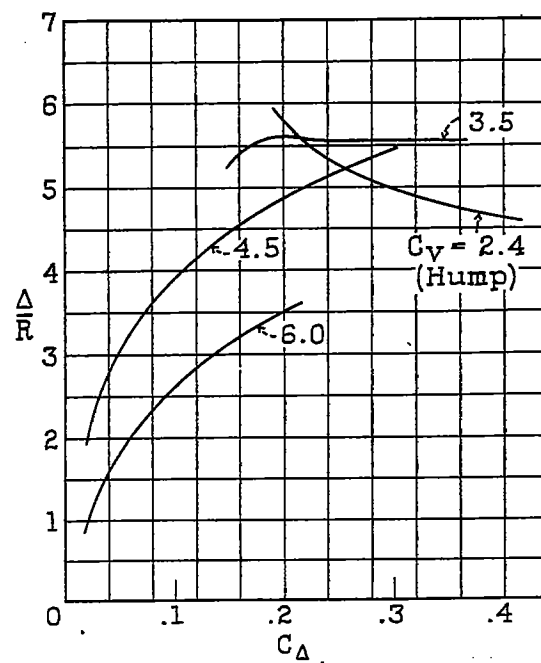
Figure 36.—Model 12. Effect of C_Δ on Δ/R at best trim angles.
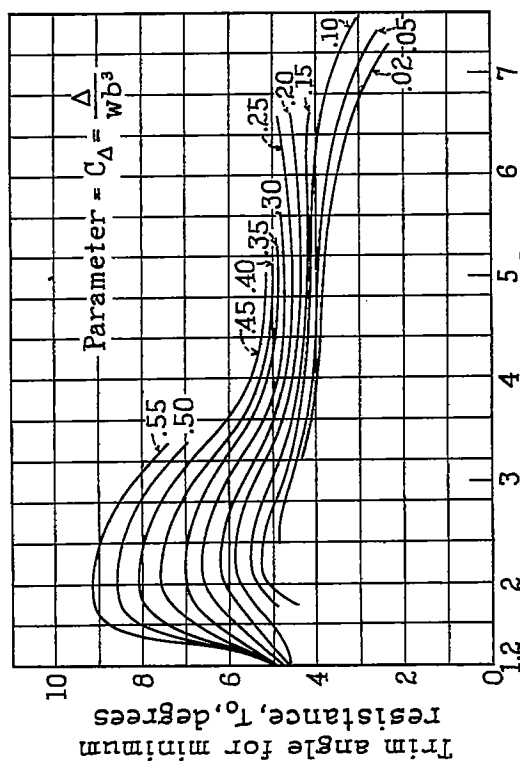
Fig. 34.—Model 11-A. Trim angle for minimum resistance.
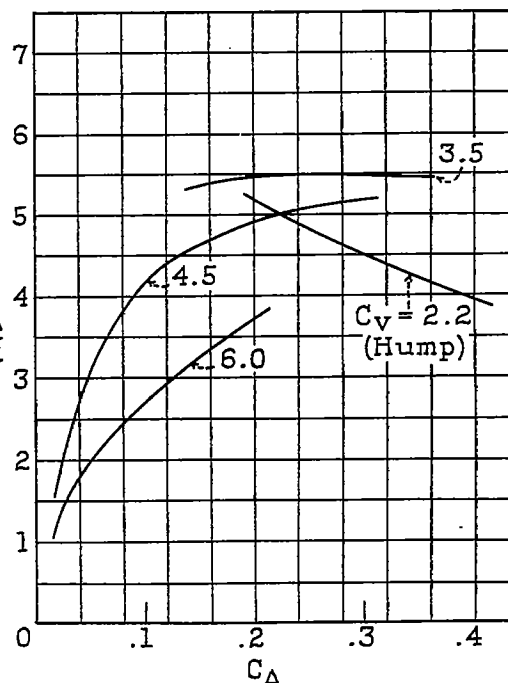
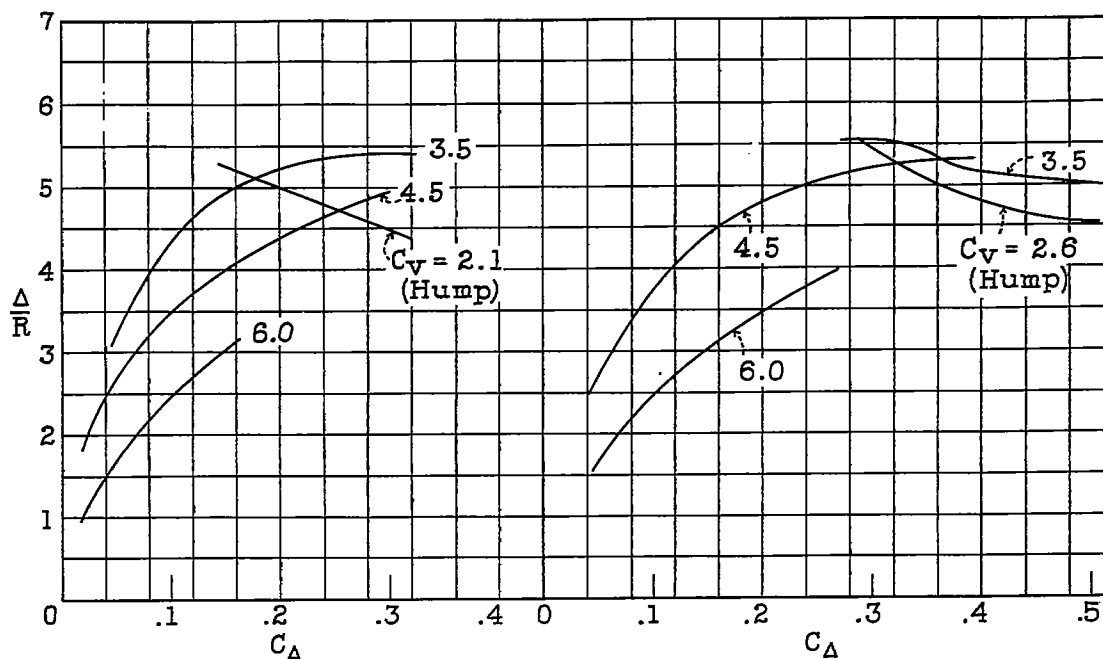Fig. 37.—Model 13. Effect of C_Δ on Δ/R at best trim angles.

Figure 38.- Model 14. Effect of
C_Δ on Δ/R at best
trim angles.

Figure 39.- Model 15. Effect of C_Δ
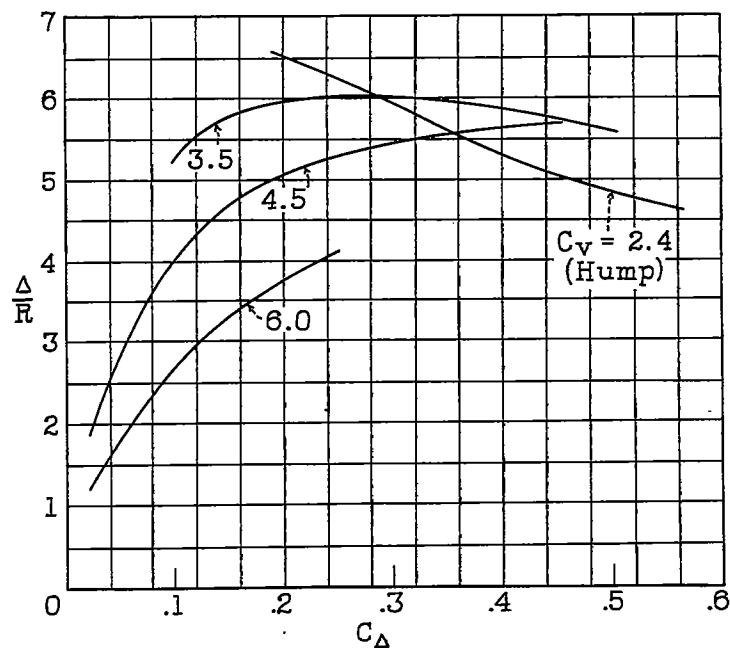on Δ/R at best
trim angles.

Figure 40.- Model 11-A. Effect of C_Δ on
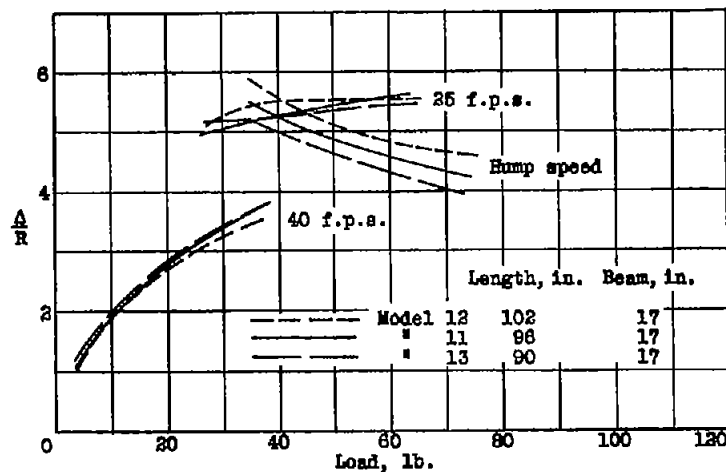Δ/R at best trim angles.

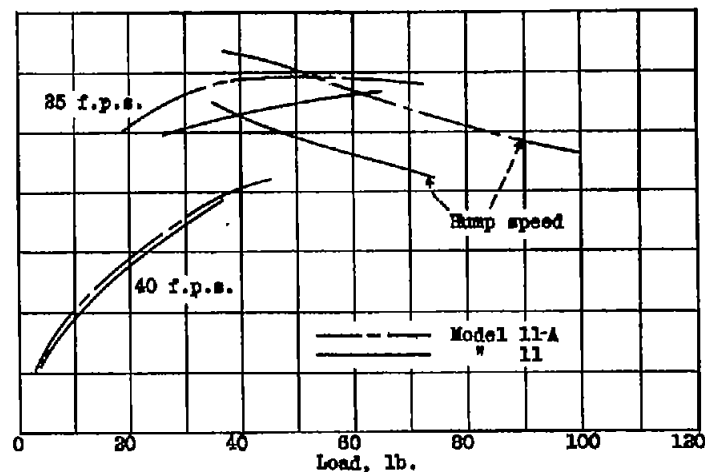Figure 41.- Effect of change in length. Models 11, 12, and 13.

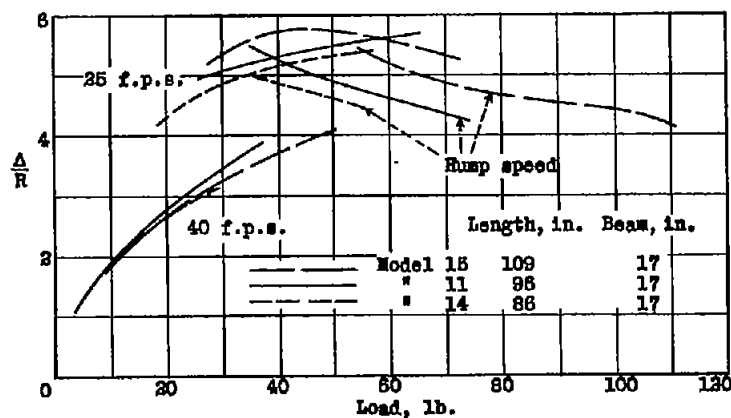Figure 43.- Effect of forebody curvature. Models 11 and 11-A.

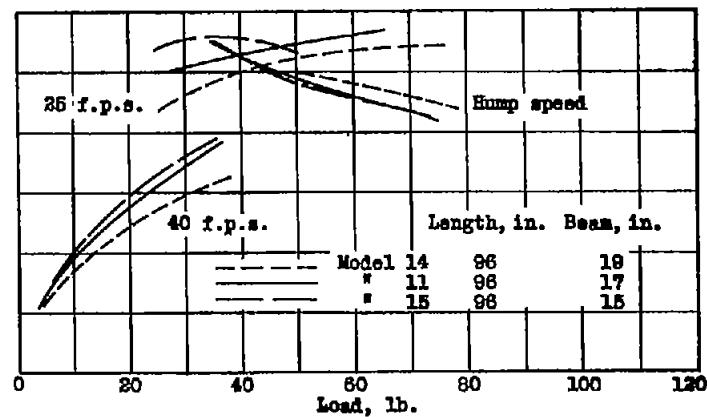Figure 42.- Effect of change in length. Models 11, 14, and 15. (Compared at the same beam)

Figure 44.- Effect of change in beam. Models 11, 14, and 15.